TITLE: Correlates of Obstacle Course Performance Among Female Soldiers Carrying Two Different Loads

Correlates of Obstacle Course Performance Among Female Soldiers Carrying Two Different Loads

P.N. Frykman, E.A. Harman, and C.E. Pandorf

U.S. Army Research Institute of Environmental Medicine
Kansas Street, Natick, MA 01760-5007, USA

Summary

To examine correlates of obstacle course performance, 11 female volunteers (mean±SD: 25.3±5.5 yrs, 166±6.5 cm, 61.3±6.7 kg) negotiated an obstacle course (low hurdles, zig-zag run, low crawl, overhead horizontal pipe, wall, and sprint) with a 14 kg fighting load and a 27 kg approach load. Predictive variables included Army physical fitness test (APFT: pushups, situps, and 3.2 km run) scores, treadmill $\dot{V}O_{2\ max}$, and anthropometric variables. For the 14 kg load, pushups and situps correlated moderately ($p<0.1$) with time to negotiate the low crawl and pipe. With the 27 kg load the APFT score correlated moderately with zig-zag and low crawl times, body height correlated ($p<0.1$) with hurdles and zig-zag times, and $\dot{V}O_{2\ max}$ correlated with zig-zag and pipe performance. Only 55% of wall traversal attempts with the fighting load and 27% with the approach load were successful, and 80% of pipe traversal attempts with the fighting load and 30% with the approach load were successful. Because so many volunteers could not negotiate these stations, times for the segments were not included in the analysis of total course time. Pushups ($r=-0.54$, $p<0.1$) and situps ($r=-0.62$, $p<0.1$) best predicted course time with the 14 kg load, while the APFT score ($r=-0.57$, $r<0.1$) best predicted time with the 27 kg load. Aerobic fitness and muscular endurance play important roles in obstacle course performance. As measures of these abilities, the total APFT score and its pushup and situp sub-scores can serve as field expedient predictors of obstacle course performance.

Introduction

A soldier must not only carry loads to a battlefield, but must sprint across obstacles on the battlefield while under fire. The ability to traverse the battlefield quickly is an important component of both individual survival and the effectiveness of the fighting unit. An obstacle course requiring movements similar to those on a battlefield presents various physical challenges not characteristic of road marching. A soldier's performance on a well-designed obstacle course is a good indication of the ability to get across a real battlefield quickly.

Studies by Jette, Kimick, and Sidney (7), Kusano, Vanderburgh, and Bishop (9), Bishop et al.(2) focused on the physiological determinants of performance on indoor obstacle courses but only in the unloaded condition. Bishop et al. (2) examined the relationship of obstacle course performance (OCP) to upper and lower body aerobic and anaerobic power, muscular strength and endurance, and anthropometric characteristics, and found low but statistically significant positive correlations between course time, body weight and % body fat (heavier and fatter people took longer), and a negative correlation of course time with $\dot{V}O_{2\ max}$ relative to body weight. The best three-variable multiple regression equation (% fat, body mass, Wingate arm peak power) from this study accounted for only 35% of the variance in course time.

Jette et al. studied the obstacle course performance of Canadian soldiers who were loaded with helmets, boots and a rifle, and found higher correlations than Bishop et al. (2). They found that better obstacle course times were associated with higher aerobic power, anaerobic power, absolute strength, and muscular endurance. Stepwise multiple regression analysis determined that these four variables accounted for 81% of the variance in obstacle course time. Jette et al. (6) and Kusano et al. (9) also found excess body fat to be a detriment to OCP.

Paper presented at the RTO HFM Specialists' Meeting on "Soldier Mobility: Innovations in Load Carriage System Design and Evaluation", held in Kingston, Canada, 27-29 June 2000, and published in RTO MP-056.

What distinguishes the study described in this paper from the above studies is that the volunteers negotiated the obstacle course carrying 2 different loads, the total obstacle course and each segment of the obstacle course were electronically timed and, unlike all the previous studies except that of Kusano et al. (9), our study used female soldiers as test volunteers.

We found it important to study the ability of women to perform combat-related tasks because 1) during basic training in the U.S. Army, all female recruits currently participate in load carriage marches and other combat maneuvers, 2) women have been well integrated into combat-support Military Occupational Specialties (MOS)s and they could easily become involved in combat if front lines shift, and 3) it is possible that ground combat MOSs may be open to women at some time in the future.

Methods

Subjects

The volunteers for this study were 11 female soldiers who were medically screened and from whom written informed consent was obtained prior to their participation. In the U.S. Army women are not currently allowed into ground combat units, so none were combat soldiers. Several had sedentary jobs, but most had jobs that were physically demanding, such as Military Police work. The data in Table 1 describes the volunteers who as a group were moderately lean women of average weight and stature.

Table 1. Descriptive Characteristics of Subjects

Variable	Mean ± SD	Range
Age (yr)	25.3±5.5	19.4-38.2
Body mass (kg)	61.3±6.7	52.5-72.0
Body fat (%)	25.7±3.22	20.6-31.5
Fat free mass (kg)	45.5±3.7	41.3-50.9
Height (cm)	166.0±6.5	154.7-174.8
Shoulder diameter (cm)	37.0±1.4	35.2-40.2
Hip diameter (cm)	32.2±2.1	29.6-36.7
Hip circumference (cm)	93.9±6.4	87.6-105.4

Load Carriage Conditions

Volunteers were tested while carrying two different loads, the fighting and approach loads. The fighting load weighed 14 kg and consisted of the battle dress uniform (BDU), boots, body armor, Kevlar® helmet, equipment belt, load-carriage vest, dummy grenades, ammunition magazines, and an M-16 rifle. The approach load included the fighting load plus 13 kg of weight in a backpack, totaling 27 kg. The backpack used in testing was the standard external-frame Army packs (Figure 1).

Figure 1. Fighting load (14 kg) Approach load (27 kg)

The location of the center of mass of a backpack has been shown previously to affect energy cost by as much as 24% (10). In that study the best placement of the pack center of mass for minimizing the energy cost of load carriage was as close as possible to the center of mass of the person carrying the pack. That means the load should be as close to the persons back as possible and centered across the shoulder blades. The fighting load and approach load configurations were based on commonly used infantry loads. Once these configurations were established they remained unaltered for the duration of the study. The 3-dimensional location of the center of mass for each of these load conditions was determined using a balance board. The center of mass of the 14 kg load system was actually located 2-3 cm anterior of the subject's chest. For the 27 kg load, the center of mass was slightly anterior of the frame of the backpack. These center of mass locations do not take into account the weapon carried in the hands in front of the body, which would bring the load center of mass even further forward.

Independent Variables

The independent variables in this study were maximal oxygen uptake, anthropometric measures and the U.S. Army's physical fitness test.

Oxygen uptake was measured using a continuous, uphill, grade-incremental, treadmill protocol and a computerized open circuit spirometry system, which measured the rate of oxygen consumption and ventilation. The first test stage was a warm up with the volunteer running for 5 minutes at 5 miles per hour with the treadmill bed horizontal. After a 5 minute rest off the treadmill, the volunteer returned to the treadmill, donned the nose clip and mouthpiece for gas sampling, and started running on a 5% uphill grade at a speed determined to be moderate based on heart rate during the warm-up run. For the remainder of the test, the mouthpiece was kept in continuously and oxygen uptake was calculated every 30 seconds. Every 3 minutes the treadmill grade was increased by 2% without changing the treadmill speed. The test duration was typically 10-12 minutes.

The following anthropometric variables were evaluated as predictors of load carriage and obstacle course performance: age, height, body mass, biacromial and bitrochanteric diameters, hip circumference, percent body fat determined from skinfolds (4), and lean body mass.

All soldiers in the US Army are required to take the Army Physical Fitness Test (APFT) twice a year (3). The self-reported results of the volunteers' most recent physical fitness tests were analyzed to determine if they were useful predictors of obstacle course performance. The three components of the test are the maximum number of sit-ups completed in 2 minutes, the maximum number of push-ups completed in 2 minutes, and time taken to run 3.2 km. The absolute scores on the three subtests are assigned points that are scaled according to the soldier's age and sex, and these three subtest scores are added to get the total APFT score. An advantage of using APFT test data is that soldiers train for the test and are motivated to do well because a good score helps their chances for promotion.

Dependent Variables

The dependent variables for this study were the total time taken to complete the obstacle course and the times for each individual obstacle (Figure 2.). Subjects were timed negotiating a 6-station obstacle course with the 14 and 27 kg loads. The course was developed to evaluate the soldier's ability to traverse simulated battlefield obstacles rapidly while carrying combat equipment. An electronic timing system (Brower Timing Systems, Salt Lake City, Utah) was used to time the total course and each of the obstacles.

The volunteers began the course from a cued standing start with the first obstacle being a set of five 46 cm high plastic hurdles, spaced 2.1 m apart. The second obstacle required the subjects to run a zigzag pattern through a field of 9 plastic cones staggered such that adjacent cones were 1.5 m apart laterally and 3.4 m apart along the 26.8 m length of the course segment. Third was a low-crawl obstacle made of wood and rope, 61 cm high, 91 cm wide, and 3.7 m long. Without a backpack on, the volunteers could crawl on their hands and knees, but with a pack on they had to stay close to the ground and move along in a crab-like manner.

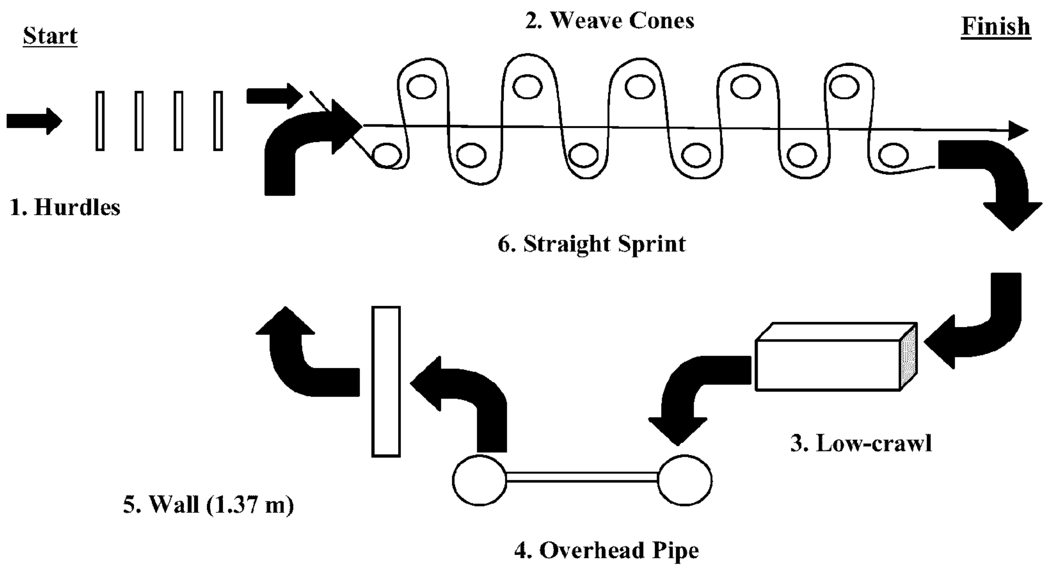

Figure 2. Plan of the obstacle course.

After the low-crawl, the volunteer proceeded to a horizontal pipe 3.7 m long suspended 1.42m above the ground. The subjects traversed the length of the pipe while hanging by their hands and feet. The majority of the weight was supported by the hands and arms, which also had to be used to pull the body along the pipe.

The importance of upper body strength became especially evident when the subject was wearing the heavier approach load. The legs provided some support, but mainly for the lower body. The pipe was divided into four equally spaced zones, and the last zone the subject reached was recorded. Because many of the volunteers could not completely traverse the pipe, the distance they traversed along the pipe before touching the ground, was also used to describe their performance. The fifth obstacle was a 137 cm high smooth wooden wall without footholds or ropes. The most common technique for getting up and over the wall was to place the hands on top of the wall and push down while jumping up high enough to get the torso and one leg on top of the wall, then dropping down over the other side. Spotters stood by to prevent subjects from landing headfirst. The movement involved mainly leg power. Since most attempts by the women to traverse the wall were failures, the criteria for judging performance on this obstacle was whether or not the volunteers succeeded at traversing the wall rather than the traversal time. Subjects finished the obstacle course with a 28.7 m straight sprint.

The test volunteers were instructed on how to complete each obstacle and given time to practice maneuvering through the various segments of the course. The test volunteers performed 2 trials with each of the 2 loads on the obstacle course with the presentation of loads balanced over the volunteers to eliminate order effects.

Results

Table 2 presents aerobic fitness and physiological performance data describing the test volunteers. The volunteers were more aerobically fit than the average female of their age according to normative data (1). $\dot{V}O_{2\,max}$ (ml/kg/min) ranged from 41.9 to 54.4, which represents the 80-99th percentile for females age 20 to 29.The APFT score ranged from a low of 216 for the most sedentary individual to a high of 290 out of 300 possible points. Essentially this was a group of average sized, relatively lean, aerobically fit women.

Table 2. Physiological and physical performance characteristics of test subjects.

Variable	Mean ± SD	Range
$\dot{V}O_{2\,max}$ (ml/kg/min)	48.8±4.6	41.9-54.4
$\dot{V}O_{2\,max}$ (L/min)	3.0±0.5	2.4-3.7
3.2 km run time (min)	17.0±1.1	14.7-18.3
Push-ups (#)	41±12	26-64
Sit-ups (#)	68±10	54-85
APFT score (pts)	256±24	216-290

Obstacle Course Times

Table 3 shows the times to complete each station of the obstacle course with the 14 and 27 kg loads. It took subjects from 12 to 26 % longer to traverse the hurdles, zigzag, and straight sprint events with the 27 kg load than with the 14 kg load. The biggest difference was seen with the low-crawl obstacle, which took more than twice as long to negotiate with the 27 kg load than the 14 kg load.

The volunteers had a difficult time traversing the full length of the horizontal pipe obstacle and clearing the 137 cm high wall. While traversing the horizontal pipe with the 14 kg load, all but two of the subjects were able to complete the task in both of the trials they performed, and 80% of the trials were successes. With the 27 kg load the volunteers were only able to successfully traverse the full length of the pipe in 30% of the trials. On average, the subjects were only able to pull themselves to just over the halfway mark (57% of the length) of the pipe. Only 55% (6 of 11) of the subjects were able to make it over the wall with the 14 kg load and only 27% (3 of 11) cleared it with the 27 kg load. Because such a large percentage of subjects either took too long a time or were unable to complete these two obstacles at all, we removed the times for these two obstacles from the total course time.

Table 3. Obstacle Course Times (s)*

Obstacle	14 kg load Mean ± SD	Range	27 kg load Mean ± SD	Range	% increase in time with the heavier load
Hurdles	5.4±0.52	4.6 – 6.3	6.8±1.0	5.6 – 9.3	25.9
Zigzag	10.2±0.84	8.8 – 11.7	11.4±1.1	9.8 – 13.9	11.8
Low-crawl	12.2±2.3	9.0 – 16.8	25.3±6.3	16.2 – 37.5	107.4
Straight sprint	8.8±0.74	7.4 – 9.5	10.3±1.2	8.5 – 12.5	17.0
Course total*	36.5±3.6	30.3 – 43.1	53.9±8.4	41.7 – 73.1	47.7

* does not include the wall and pipe times

With the 14 kg load, taller volunteers were more successful at getting over the wall than were the shorter volunteers. Of the seven women who made it over the wall with the 14 kg load, six of them were the tallest in the group. Of the five women who made it over the wall with the 27 kg load, four of them were the tallest of the 11 volunteers. (As it turns out, it was not the same shorter subject who cleared the wall with both the 14 kg and 27 kg loads.)

Correlates of Obstacle Course Performance Time

The correlation coefficients of various independent measures with obstacle course time are shown in Table 4. It should be noted that, because a shorter time for the course or any of its segments indicates better performance, a negative correlation indicates that higher scores on that measure were associated with shorter times and, thus, greater speed.

Table 4. Correlates of Obstacle Course Performance Time

Obstacle	14 kg load	27 kg load
Hurdles	Hip diameter ($r = 0.56$)$^{\#}$ Hip circumference ($r = 0.58$)$^{\#}$	Height ($r = -0.69$)*
Zigzag run		Age ($r = -0.66$)* Height ($r = -0.54$)$^{\#}$ $\dot{V}O_{2\,max}$ (ml/kg/min) ($r = -0.55$)$^{\#}$ APFT score ($r = -0.59$)$^{\#}$
Low-crawl	Push-ups ($r = -0.59$)$^{\#}$ Sit-ups ($r = -0.60$)$^{\#}$	Sit-ups ($r = -0.55$)$^{\#}$ APFT score ($r = -0.67$)*
Pipe length completed	APFT score ($r = 0.57$)$^{\#}$ Push-ups ($r = 0.58$)$^{\#}$ Sit-ups ($r = 0.64$)*	$\dot{V}O_{2\,max}$ (ml/kg/min) ($r = 0.55$)$^{\#}$
Course total	Push-ups ($r = -0.54$)$^{\#}$ Sit-ups ($r = -0.62$)$^{\#}$	APFT score ($r = -0.57$)$^{\#}$

*$p<0.05$ $\quad$ $^{\#}p<0.1$

Hurdles. With the 27 kg load, greater body stature was associated with faster times over the hurdles (r=-0.69). This is likely related to taller individuals having longer leg length, and being able to more easily step over the hurdles. Individuals with longer legs would take fewer steps between hurdles, which could possibly result in faster times.

Zig-zag. None of the independent measures were significantly correlated with 14 kg load and time for the zigzag run. For the 27 kg load, age ($p<0.05$), height ($p<0.09$), relative $\dot{V}O_{2\ max}$ ($p<0.08$) and APFT score ($p<0.06$) correlated with zigzag run time.

Low-crawl. Volunteers who could do more push-ups ($p<0.06$) and more sit-ups ($p<0.07$) proved better at the low-crawl obstacle with the 14 kg load. Sit-ups again showed importance with the 27 kg load ($p<0.1$) as did APFT score ($p<0.03$). The large difference in completion time for the low-crawl between the two loads is probably due to a difference in crawling position. With the 14 kg load there was room to crawl through the obstacle up on the hands and knees. In regard to the upper body, the position of support for the crawl is nearly the same as when doing push-ups. Given this position, it is not surprising that pushup endurance proved a good predictor of performance. The low-crawl position used with the 27 kg load, the abdomen and chest were in direct contact with the ground allowing the subjects to maneuver beneath the roof of the obstacle. This movement technique was much more strenuous than that used with the 14 kg load and is probably one of the reasons why it took subjects more than twice as long to complete this obstacle with the 27 kg load than with the 14 kg load.

Because it was necessary for the subject's chest to be in contact with the floor they did not have to support their body mass using their upper body strength. Thus, upper body strength wasn't as important as it was with the 14 kg load. It is not surprising that pushup endurance did not correlate well with low-crawl time when carrying the 27 kg load.

Pipe. APFT score was a predictor of pipe performance with the 14 kg load ($p<0.07$). The fact that two-thirds of the APFT score is based on pushup and sit up performance, each of which is moderately well correlated with pipe obstacle performance (push-ups: $p<0.07$; sit-ups: $p<0.05$), accounts for the predictive value of the APFT score. The 3.2 km run component of the APFT score did not correlate well with pipe traversal time. With the 27 kg load, relative $VO_{2\ max}$ was the only variable to correlate well ($p<0.08$) with pipe traversal performance.

Sprint. None of the independent variables related well to the sprint segment.

Total course time. Subjects who did more push-ups ($p<0.09$) and sit-ups ($p<0.06$) had faster times for the total course with the 14 kg load. Higher APFT scores ($p<0.07$) were related to faster total course completion times with 27 kg load.

Discussion

A unique aspect of the study was the inclusion of two loaded conditions for assessing performance on the obstacle course. Muscular endurance scores, quantified as maximum number of push-ups and sit-ups performed, were the only independent measures that correlated well with obstacle course total time for the 14 kg load. For the heavier load, height, $\dot{V}O_{2\ max}$ and APFT score correlated fairly well with performance on some individual obstacles. The fact that $\dot{V}O_{2\ max}$ became a factor with the heavier load, when it wasn't for the lighter load, may be due to the fact that the heavier load lengthened course completion time to where aerobic metabolism accounted for a significant enough percentage of energy consumption.

Body fat was not found to be a major detriment to OCP. Neither percent body fat nor fat mass correlated significantly with obstacle course time. The findings of Kusano et al. (9) contrasted with ours in that they found body fat to be related to obstacle course performance. Their subjects ran their obstacle course unencumbered by external loads. The addition of loads in the range of 14–27 kg may be large enough to significantly alter the relationship that Kusano (9) found. While the subjects in our study would not be considered excessively lean, they were representative of the population of female soldiers at the end of the basic combat training course (% body fat =25.6, Sharp, et al.)(12) In addition, fat free mass and fat mass were positively correlated (r=.70); the volunteers who had greater fat mass also had greater fat free mass. For this reason, it is likely that subjects with greater fat mass were able to carry the extra fat without a decrease in performance compared to smaller, leaner subjects. Rayson et al. (11) also found in a pooled gender model that greater levels of body fat were associated with improved load carriage performance with a 15 kg load. However, because fat provides no benefit in itself to lifting or carrying heavy loads, it is likely that the subjects who did well carrying the backpack loads would do even better if they lost body fat, assuming that they could maintain their fat free mass.

The utility of total and component APFT scores for predicting obstacle course performance was apparent. With the 14 kg load, the greater numbers of push-ups and sit-ups performed were associated with faster times for the pipe, low-crawl, and total course. With the 27 kg load, a higher APFT score was associated with faster performance on the zigzag, low-crawl and total course. As components of the APFT, numbers of sit-ups and push-ups performed were related (r=0.60 for each) to APFT score. In contrast to other variables, the APFT variables maintained their association with low-crawl and total course performance across loads. There were two other independent measures that correlated with more than one course segment. With the 27 kg load, taller individuals performed better on the hurdle, zigzag, and wall obstacles (height was also important with 14 kg loaded wall performance); relative $\dot{V}O_{2\ max}$ correlated well with zigzag and pipe performance.

The fact that most of the correlations of the independent variables with OCP were only moderate in magnitude may be explained by the fact that the obstacle course involves a unique and complex blend of physiological, biomechanical, and mental abilities. Our findings in this regard agree with those of Kraemer et al. (8), and Bishop et al. (2). who suggested that high degrees of certainty for prediction of complex task performance might not be possible using a battery of simple anthropometric and fitness measures. Jette et al. (7) found higher correlations between aerobic power and OCP than we did. This may be due to the fact that the obstacles in their course of a much longer duration than ours.

In our previous studies men have not had a problem in clearing the wall (5). Based on body center of mass (COM) data by Winter (13) the female subjects had to raise their COM an average of 40 cm to clear the wall. In contrast it was estimated that the men only had to raise their COM 33 cm or 18% less than the females. Further examination of the COM location for the 27 kg load from this study and our earlier study with male volunteers reveals that the distance that women had to raise the load's COM was 11.6 cm, whereas the men had to raise it only 1.8 cm. The women's 27 kg load represented 44% of their body mass, and the men's represented just 31% of their body mass. The women were at a considerable disadvantage compared to the men, with their body COM and the pack COM further below the top of the wall, combined with pack's greater proportion of their body mass. It is clear that a volunteer tall enough has an advantage in wall clearing in that they would not need to be as strong in order to get their center of mass over the wall. As a result most women were unable to clear the wall.

Conclusions

The results of this study demonstrate that the APFT and two of its components, sit-ups and push-ups, which are measures of muscular endurance, showed predictive value for many of the obstacle course segments. This was true with both the light and heavy loads. Aerobic fitness and muscular endurance as expressed by the APFT score play important roles in obstacle course performance and could serve as field expedient predictors of obstacle course performance.

The other independent variables examined in this study, with the notable exception of aerobic fitness, and body stature, showed little or no predictive power. The complex nature of obstacle course performance makes it very difficult to use uncomplicated anthropometric, physiological or performance variables as stand-alone predictors of overall obstacle course performance.

References

1. American College of Sports Medicine (1995), ACSM's Guidelines for Exercise Testing and Prescription(Fifth Edition), p116, Williams and Wilkins, Baltimore.

2. Bishop, P.A., Fielitz, L.R., Crowder, T.A., Anderson, C.L., Smith, J.H. & Derrick, K.R. (1999). Physiological determinants of performance on an indoor military obstacle course test. Military Medicine, 164, 891-896.

3. Department of the Army, Headquarters. (1992). Physical fitness training. Washington, D.C., FM 21-20. U.S. Government Printing Office.

4. Durnin, J.V.G.A. & Womersley, J. (1974). Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. British Journal of Nutrition, 32, 77-97.

5. Harman, E., Frykman, P., Pandorf, C., Tharion, W., Mello, R., Obusek, J., & Kirk, J. (February 1999). Physiological, biomechanical, and maximal performance comparisons of soldiers carrying loads using U.S. Marine Corps Modular Lightweight Load-Carrying Equipment (MOLLE), and U.S. Army Modular Load System (MLS) prototypes. (USARIEM Technical Report T99-4). Natick, MA: United States Army Research Institute of Environmental Medicine.

6. Jette, M., Kimick, A. & Sidney, K. (1989). Evaluating the occupational physical fitness of Canadian forces infantry personnel. Military Medicine, 154, 318-322.

7. Jette, M., Kimick, A. & Sidney, K. (1990). Evaluation of an indoor standardized obstacle course for Canadian infantry personnel. Can J Sport Sci, 15, 59-64.

8. Kraemer, W.J., Nindl, B.C., Gotshalk L.A., Harman F.S., Volek, J.S., Tokeshi, S.A., Meth, S., Bush, J., Etzweiler, S.W., Fredman, B.S., Sebastianelli, W.J., Putukian, M., Newton, R.U., Hakkinen, K. & Fleck S. (1998). Prediction of militarily relevant occupational tasks in women from physical performance components. In S. Kumar (Ed.), Advances in Occupational Ergonomics and Safety (pp. 719-722). Burke, VA: IOS press.

9. Kusano, M.A., Vanderburgh, P.M., & Bishop, P. (1998). Impact of body size on women's military obstacle course performance. In S. Barrett & C. Wright (Eds.), Biomedical Sciences Instrumentation Vol. 34. Proceedings of the 35th annual Rocky Mountain Bioengineering Symposium & 35th International ISA Biomedical Sciences Instrumentation Symposium (pp. 357-362).

10. Obusek, J.P., Harman, E.A., Frykman, P.N., Palmer, C.J., & Bills, R.K. (1997). The relationship of backpack COM location to the metabolic cost of load-carriage [abstract]. Med Sci Sports Exerc, 29(5):S205.

11. Rayson, M., Holliman, D. & Belyavin, A. (2000). Development of physical selection procedures for the British Army. Phase 2: relationship between physical performance tests and criterion tasks. Ergonomics, 43, 73-105.

12. Sharp, M.A., Knapik, J.J., Patton, J.F., Smutok, M.A., Hauret, K., Chervak, M., Ito, M., Mello, R.P., Frykman, P.N., Jones, B.H.(2000). Physical Fitness of Soldiers Entering and Leaving Basic Combat Training. (USARIEM Technical Report T00-13). Natick, MA: United States Army Research Institute of Environmental Medicine.

13. Winter, D.A. (1979). Biomechanics of Human Movement. New York: John Wiley and Sons.

This page has been deliberately left blank

Page intentionnellement blanche